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AERODYNAMIC CHARACTERISTICS OF SEVERAL PROPOSED VERSIONS OF THE SATURN V LAUNCH VEHICLE AT MACH NUMBERS 1.57 TO 4.65

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SUMMARY

An investigation has been conducted in the Langley Unitary Plan wind tunnel to determine the aerodynamic characteristics of several proposed Saturn V launch configurations. The investigation included tests to determine the aerodynamic characteristics of several proposed upper-stage spacecraft systems in the presence of the lower two stages of the Saturn launch vehicle. The tests were conducted at Mach numbers from 1.57 to 4.65, at angles of attack from about $-9°$ to $18°$, and at a Reynolds number per foot of 2.5×10^6 and 2.3×10^6.

The results indicate that the basic third-stage spacecraft system has the lowest normal-force-curve slope of the four systems investigated and thus may have lower structural moments when combined with the lower stages. Nozzle shrouds as well as fins on the first stage have a significant stabilizing effect.

INTRODUCTION

The National Aeronautics and Space Administration is currently studying methods of integrating Saturn launch vehicles with the Apollo spacecraft. One system under current investigation is the three-stage-to-escape Saturn V vehicle for which several configurations have been proposed. The first stage and the second stage are the same for all the proposed configurations. Several versions of the third stage are being studied. The space vehicle is proposed as either a one- or two-stage Apollo spacecraft configuration. As a part of an evaluation program to determine the most suitable launch vehicle, it is necessary to determine the drag and stability characteristics of the various configurations. In addition, it is also desirable to determine the forces and moments acting on the third-stage spacecraft in order to integrate this vehicle safely with the preceding stages.

Accordingly, an investigation was conducted in the Langley Unitary Plan wind tunnel on several 0.009-scale Saturn V configurations at Mach numbers from

1.57 to 4.65. The tests were performed through an angle-of-attack range from about -9° to 18° at a Reynolds number per foot of 2.5×10^6 and 2.3×10^6. Force data were obtained for the complete Saturn V models and also for the third-stage spacecraft in the presence of the first two stages. The effects of an escape tower (on the spacecraft) and of fins and shrouds (on the first stage) on the aerodynamic characteristics of the launch configurations were also investigated. In addition, brief tests were performed on a model of the first two stages in conjunction with an orbital space station. The results are presented herein with only a limited analysis.

SYMBOLS

The aerodynamic force and moment data are referred to the body-axis system (fig. 1) with the origin located at the respective balance pitch centers for all configurations (fig. 2).

A reference area, 0.069279 sq ft

C_A axial-force coefficient, $\dfrac{\text{Axial force}}{qA}$

$C_{A,c}$ chamber-axial-force coefficient, $\dfrac{\text{Chamber axial force}}{qA}$

$C_{A,0}$ axial-force coefficient at $\alpha = 0°$

C_m pitching-moment coefficient, $\dfrac{\text{Pitching moment}}{qAd}$

C_{m_α} slope of pitching-moment curve near $\alpha = 0°$, per deg

C_N normal-force coefficient, $\dfrac{\text{Normal force}}{qA}$

C_{N_α} slope of normal-force curve near $\alpha = 0°$, per deg

D diameter, in.

d reference diameter, 3.564 in.

M free-stream Mach number

q free-stream dynamic pressure, lb/sq ft

r   radius, in.

α angle of attack of model center line, deg

PROCEDURE

Test Conditions

Tests were performed at a Mach number range from 1.57 to 4.65 for all configurations investigated. The Reynolds number per foot for all Mach numbers was constant at about 2.5×10^6 for all configurations except for the space-station configuration where the Reynolds number per foot was constant at about 2.3×10^6. The dewpoint, measured at stagnation pressure, was maintained below $-30°$ F to assure negligible condensation effects. The angle of attack was varied from approximately $-9°$ to $18°$, and sideslip angle was maintained at $0°$. All tests were conducted with natural boundary-layer transition.

Measurements

The aerodynamic forces and moments of the complete vehicle configurations were measured by means of an internally mounted strain-gage balance which, in turn, was rigidly fastened to the tunnel main support system.

An internally mounted strain-gage balance was also used to determine the forces and moments of the third-stage spacecraft configuration, and this balance was attached to a sting that was rigidly mounted to the second stage of the configuration.

Balance chamber pressure was measured by means of a static orifice located in the balance cavity of each model.

CORRECTION AND ACCURACY

Angles of attack have been corrected for both tunnel flow angularity and deflection of sting and balance due to aerodynamic loads.

The axial-force coefficients are presented as gross values and have not been adjusted to correspond to free-stream static pressure acting over the base at the model. Chamber axial-force coefficients, however, were determined for the complete launch configurations (fig. 4(a)) and for the third-stage spacecraft (fig. 4(b)).

Based upon calibration and repeatability of data, it is estimated that the various measured quantities are accurate within the following limits:

M (1.57 to 3.50) . . . . ±0.015
M (3.96 to 4.65) . . . . ±0.050
α, deg . . . . ±0.10
$C_{A,c}$ . . . . ±0.0127
C_A . . . . ±0.0158
C_m . . . . ±0.0024
C_N . . . . ±0.0028

APPARATUS

Tunnel

Tests were conducted in both the low and the high Mach number test section of the Langley Unitary Plan wind tunnel, which is a variable-pressure continuous-flow tunnel. The test sections are approximately 4 feet square and 7 feet long. The nozzles leading to the test sections are of the asymmetric sliding-block type, which permits a continuous variation of test-section Mach number from about 1.4 to 2.9 in the low Mach number test section, and from about 2.3 to 4.7 in the high Mach number test section.

Models

Drawings of the 0.009-scale test models are shown in figure 2 and photographs of two configurations are presented in figure 3. The Saturn V launch configurations consist basically of an S-IC first stage and an S-II second stage in combination with one of four third-stage spacecraft systems. A gap of 0.025 inch separated the third stage from the first two stages in order that data might be obtained for the third-stage spacecraft systems only, in the presence of the lower stages.

In this paper, the third-stage spacecraft systems will be referred to by the numbering system shown in figure 2(b). System 1 and system 2 have the same spacecraft but differ in third-stage configuration. System 1 was tested with and without an escape tower. System 3 consists of a cylindrical body with a conical-shaped nose. System 4 represents a 150-foot-diameter (full-scale) space station. In addition, a launch vehicle with system 1 was tested with the first-stage cruciform fins off and also with the fins and nozzle shrouds off.

The following tabulation gives the component arrangements for the seven configurations tested:

Configuration	First-stage fins	First-stage shrouds	Third-stage system	Tower
1	On	On	1	On
2	Off	On	1	On
3	Off	Off	1	On
4	On	On	1	Off
5	On	On	2	On
6	On	On	3	Off
7	On	On	4	On

It should be emphasized that the moment centers used for computing the data for the third-stage spacecraft were at a different location for three of the four systems. (See fig. 2.)

PRESENTATION OF RESULTS

The results of this investigation are presented in the following figures:

SUMMARY OF RESULTS

A detailed discussion of results obtained in this investigation to determine the aerodynamic characteristics of several proposed versions of the Saturn V launch vehicle at Mach numbers 1.57 to 4.65 has been omitted. However, some of the more important results are pointed out.

The normal-force-curve slopes are linear for all of the complete launch configurations in the approximate angle-of-attack range of $\pm 6^{\circ}$ and vary only slightly with Mach number. (See figs. 5 and 6.) The slope of the pitching-moment curves with angle of attack varies considerably; the linearity depends on the particular configuration. There is a general tendency, however, for the

stability level to decrease with increasing Mach number (fig. 7(a)). The axial-force level is highest for the configuration with the space station (configuration 7). Removing the fins from configuration 1 (configuration 2) leads to a marked decrease in stability level at all test Mach numbers (fig. 7(b)). Removal of the shrouds (configuration 3) further decreases the stability throughout the Mach number range. Removing the escape tower (configuration 4) had little effect on the aerodynamic characteristics.

The aerodynamic characteristics in pitch of the various third-stage systems in the presence of the lower stages are presented in figures 8 and 9 and summarized in figure 10. System 1 has the lowest value of C_{N_α} throughout the test Mach number range and thus may have lower structural moments when combined with stages 1 and 2. As was indicated for the complete launch vehicle, the axial force for system 4 (configuration with space station) is considerably greater than the axial force for the other third-stage systems.

Langley Research Center,
      National Aeronautics and Space Administration,
            Langley Station, Hampton, Va., February 25, 1964.
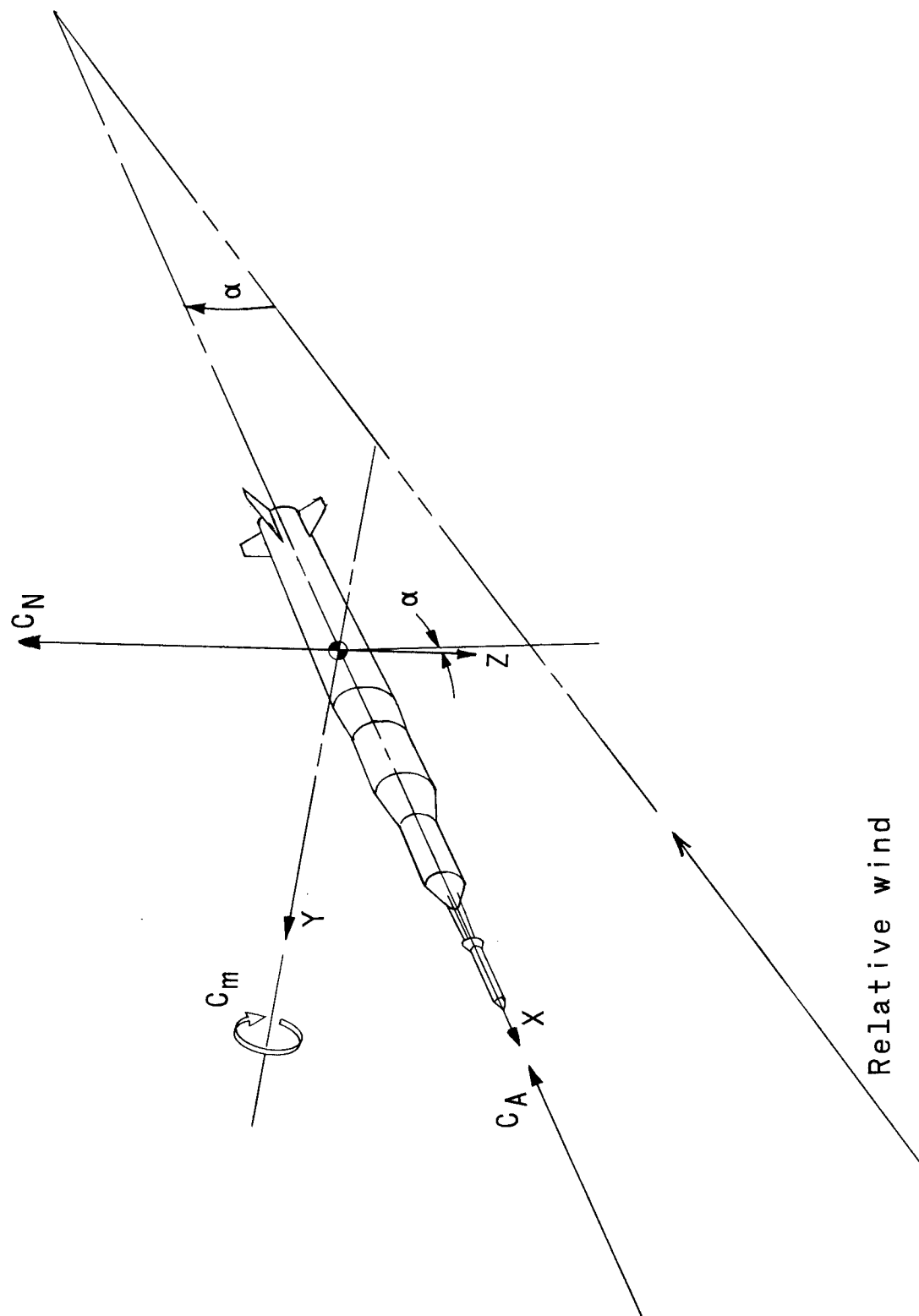
Figure 1.- Axis system. Arrows denote positive direction of forces and moments.

Stages 1 and 2

Fin and shroud details
Section A-A
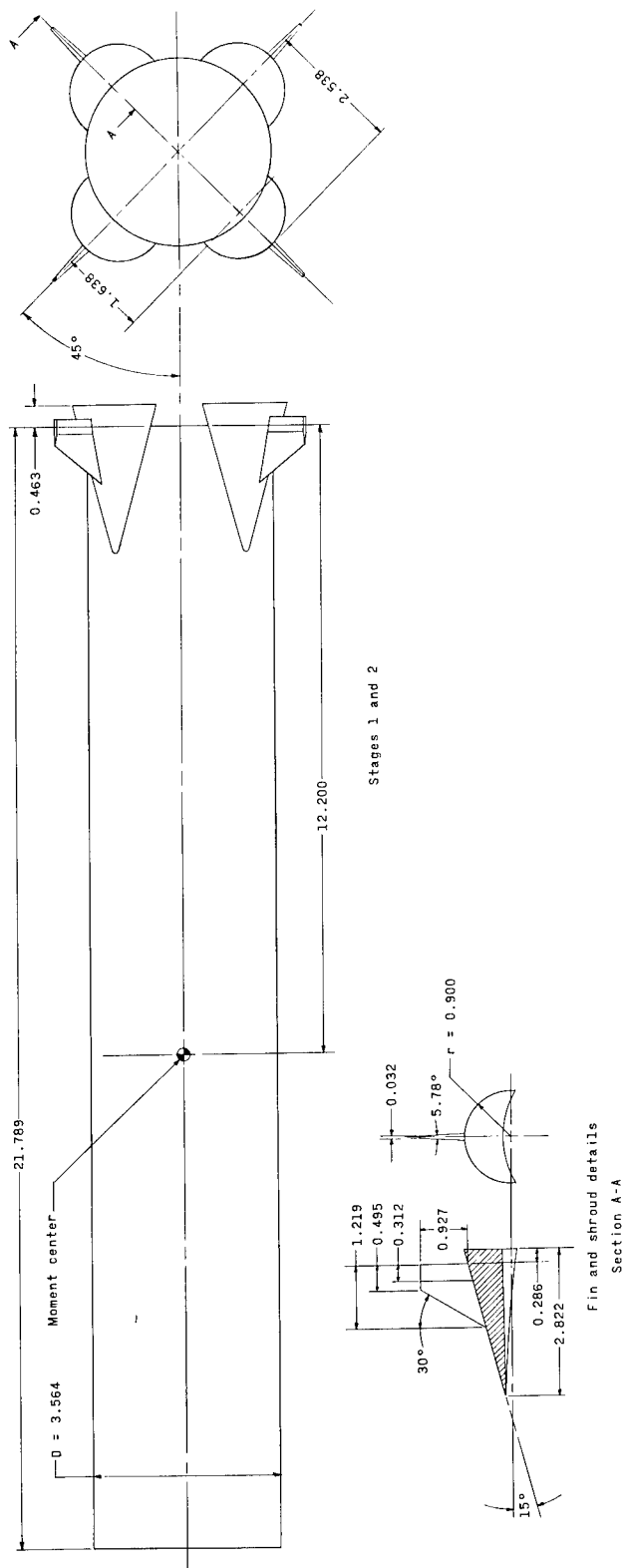
(a) Stages 1 and 2.

Figure 2.- Details of models. All dimensions are in inches unless otherwise noted.
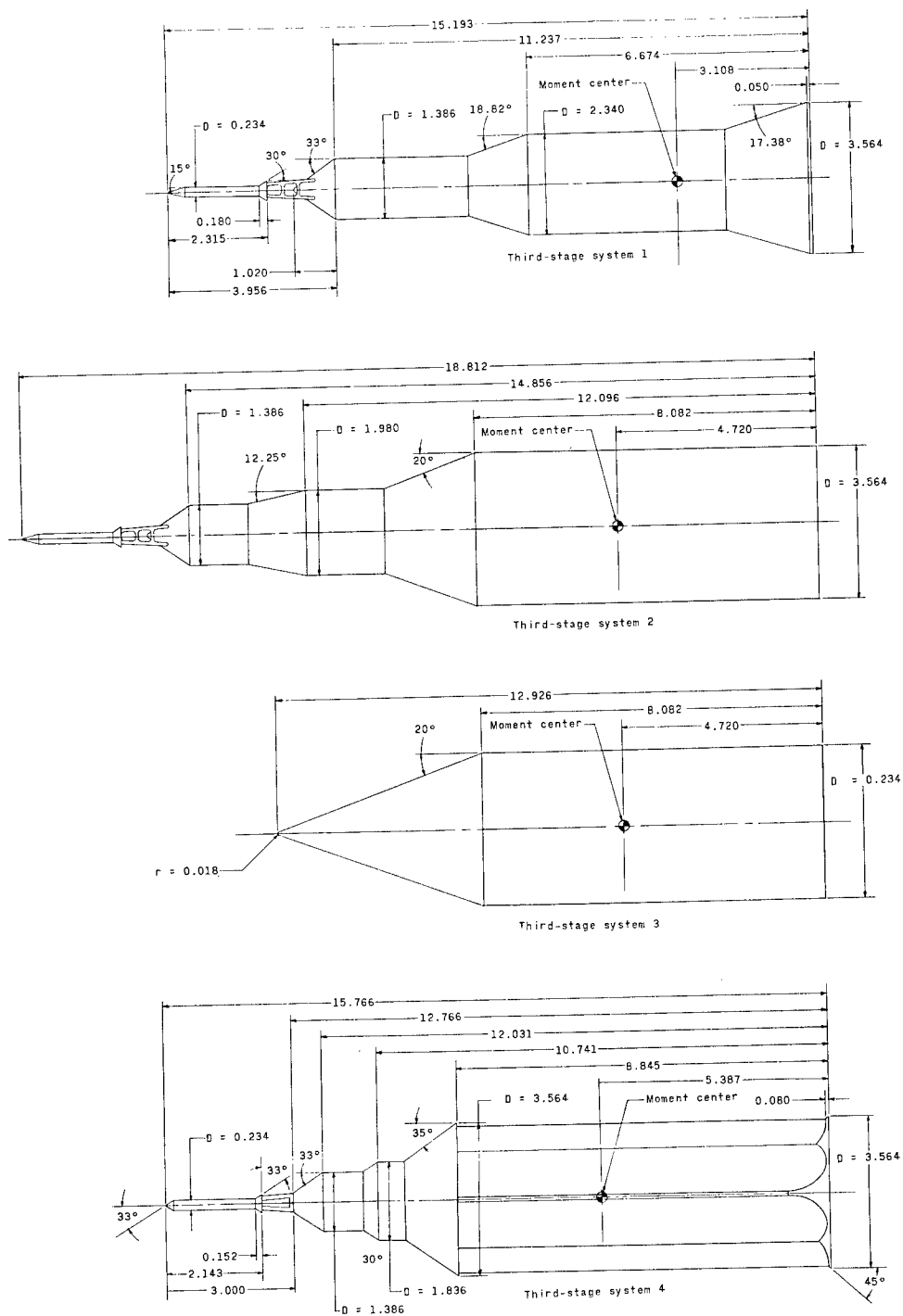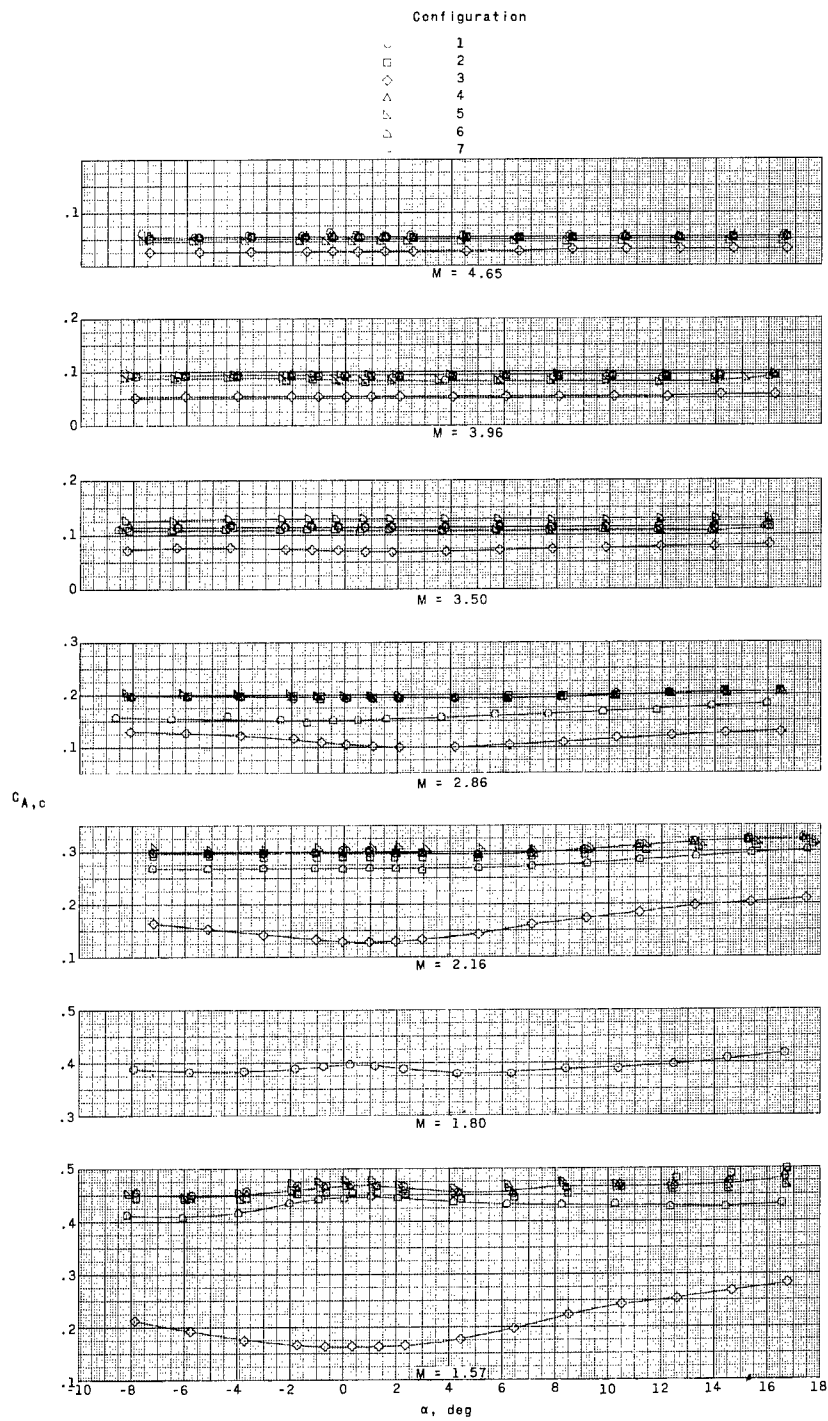
(b) Third-stage systems.

Figure 2.- Concluded.
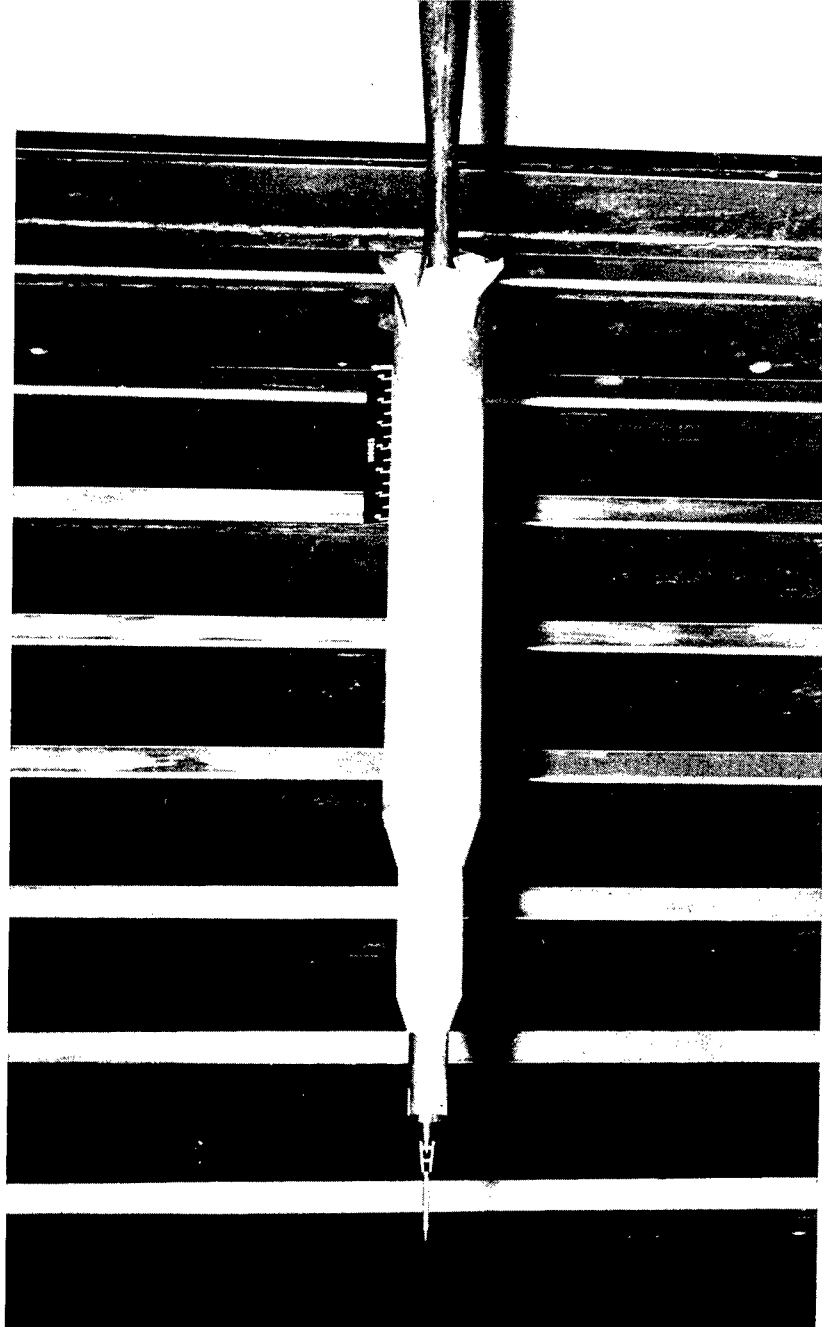
L-62-7985

(a) Launch configuration 1.

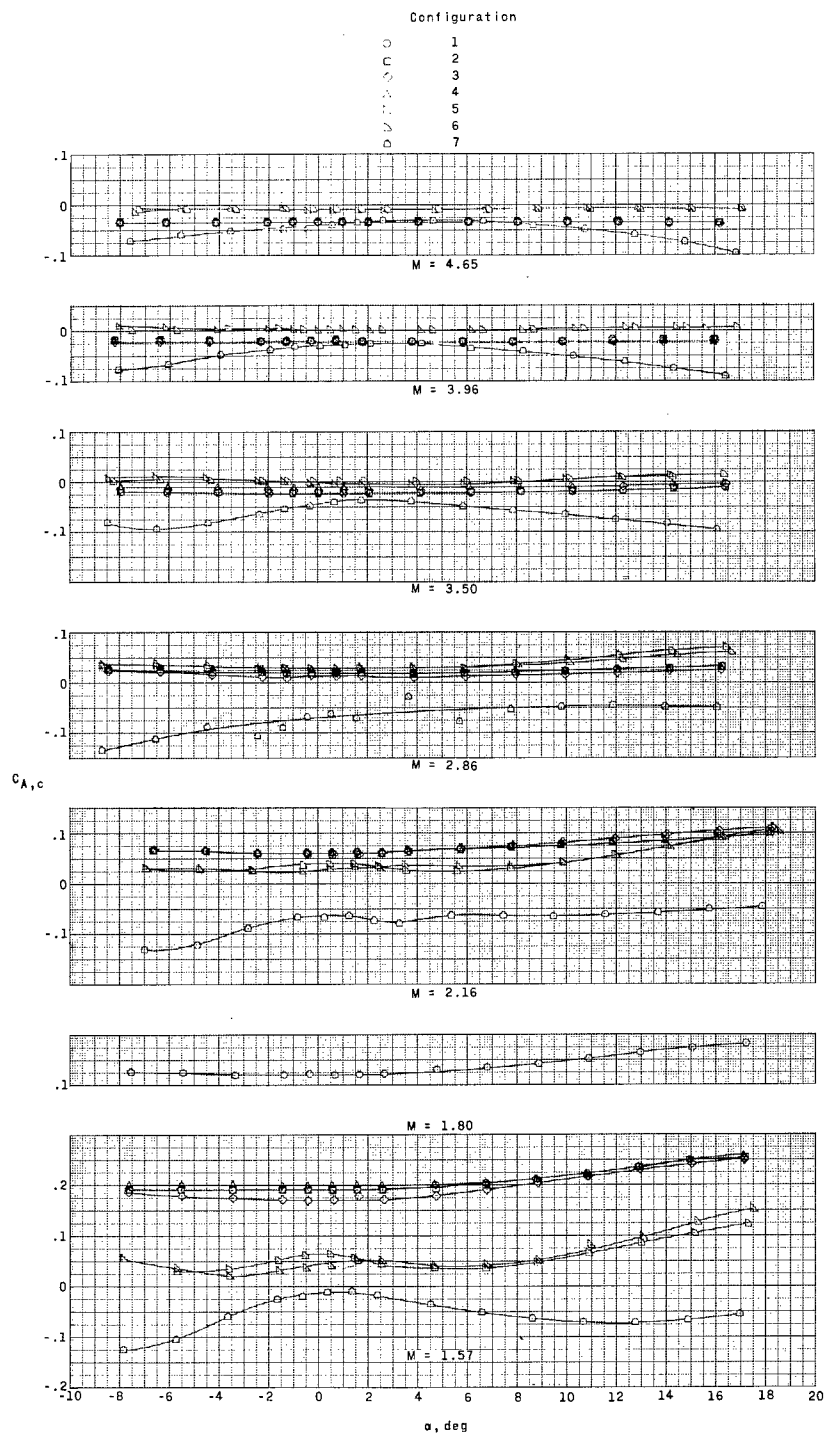Figure 3.- Photographs of some of the launch configurations tested.
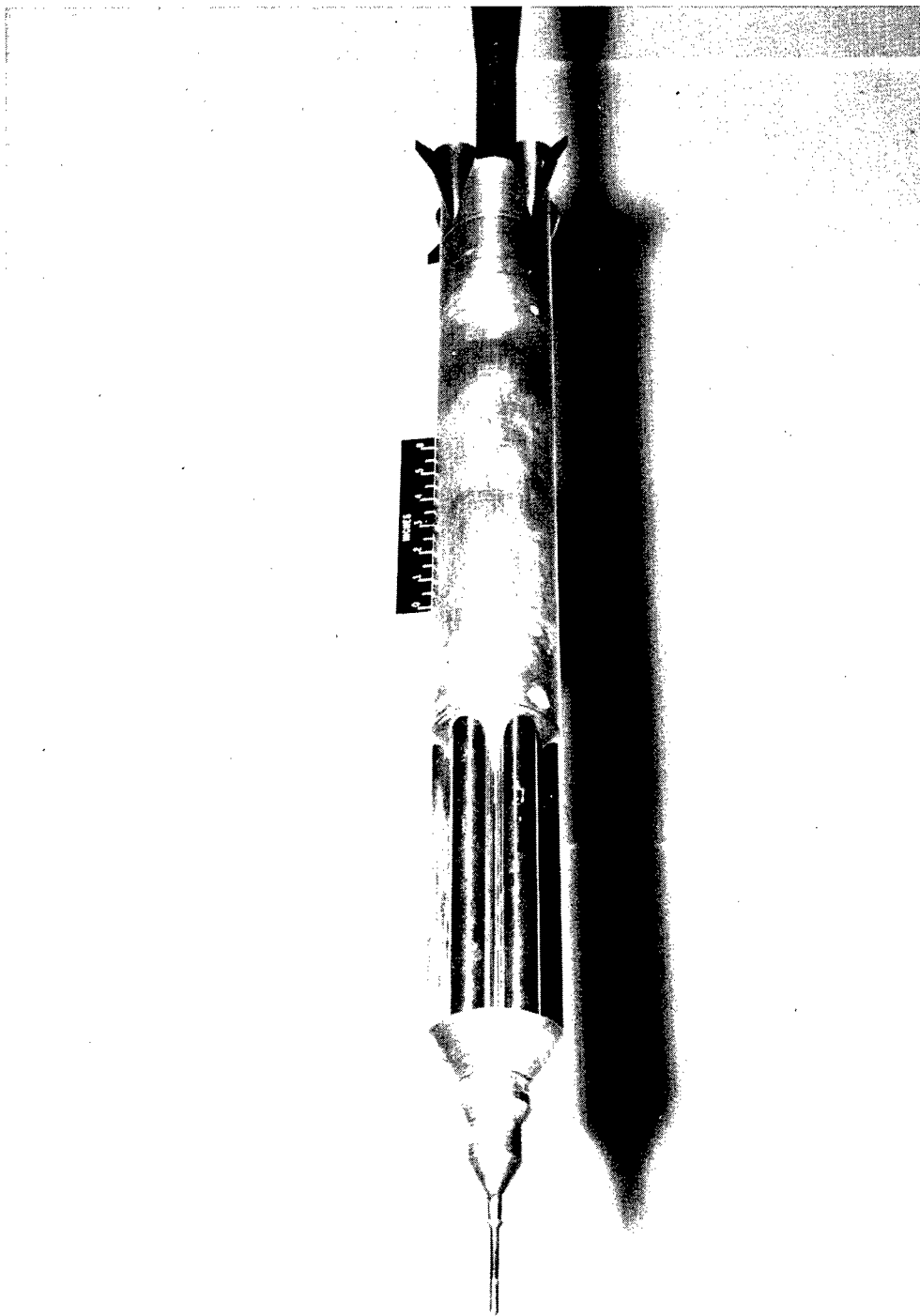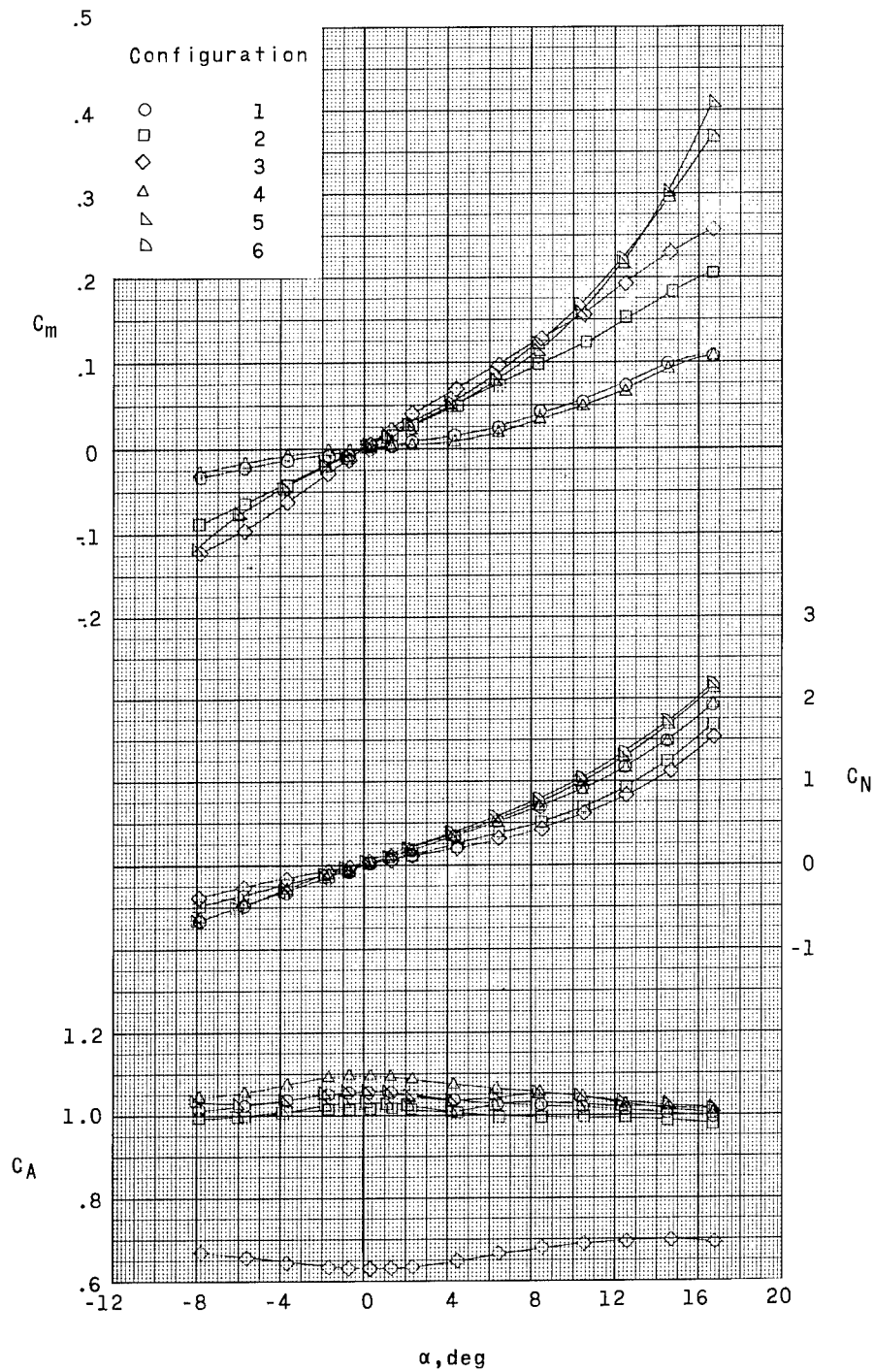
(b) Launch configuration 7.

Figure 3.- Concluded.

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(a) Launch configurations 1 to 7.

Figure 4.- Variation of chamber axial-force coefficient with angle of attack.

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(b) Third-stage spacecraft system.

Figure 4.- Concluded.

(a) M = 1.57.

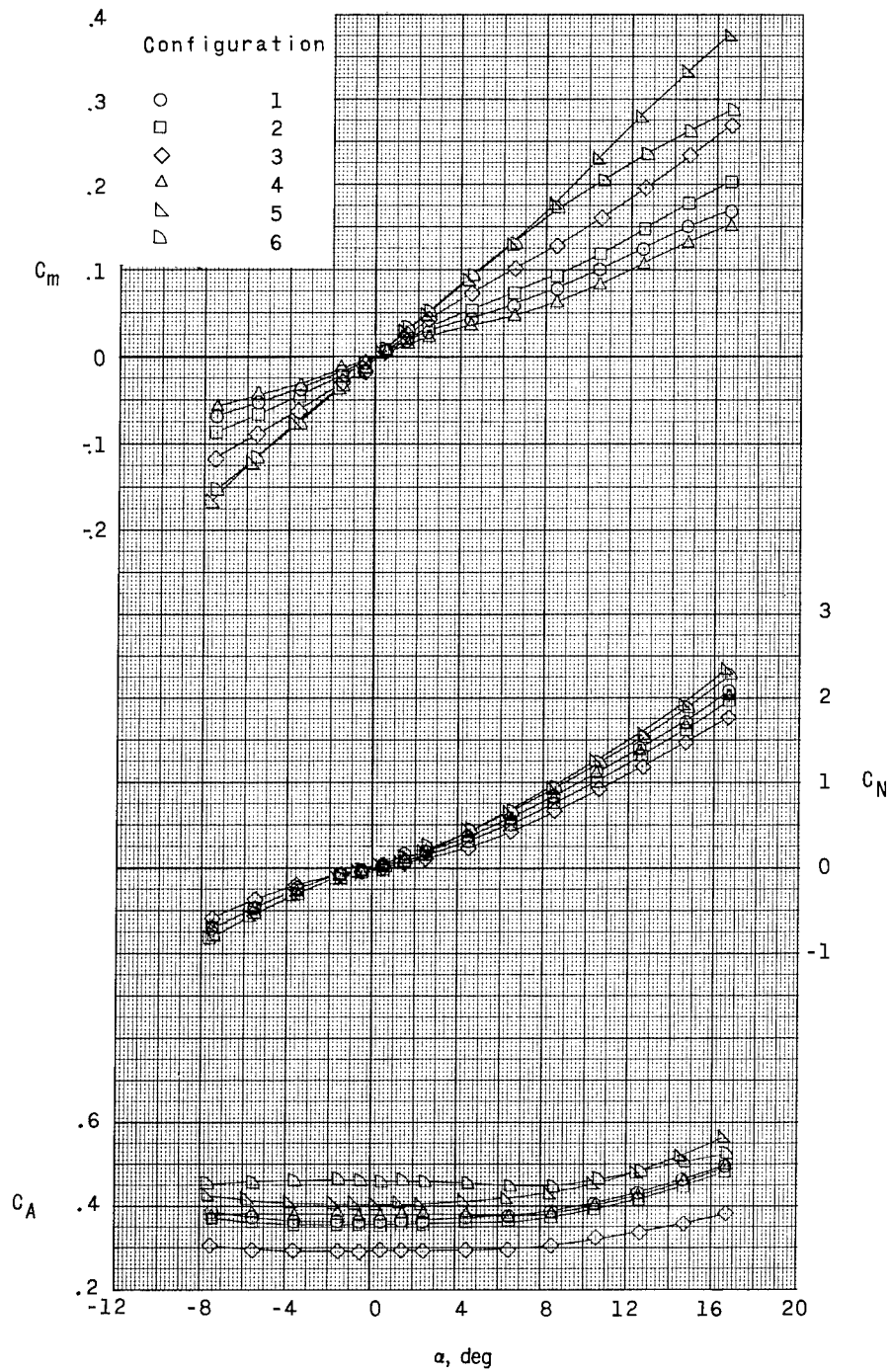Figure 5.- Aerodynamic characteristics in pitch of launch configurations 1 to 6.
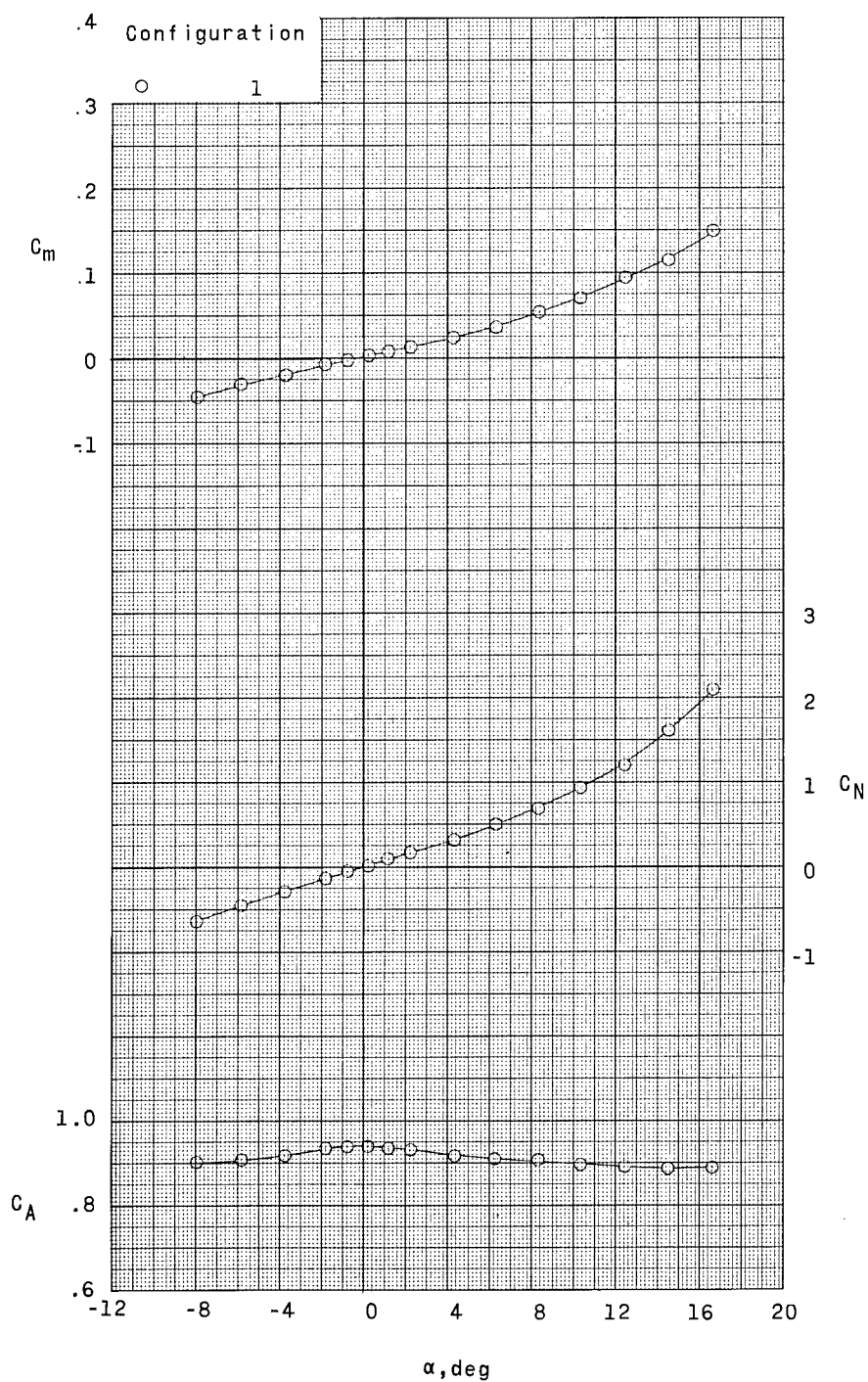
(b) M = 1.80.

Figure 5.- Continued.
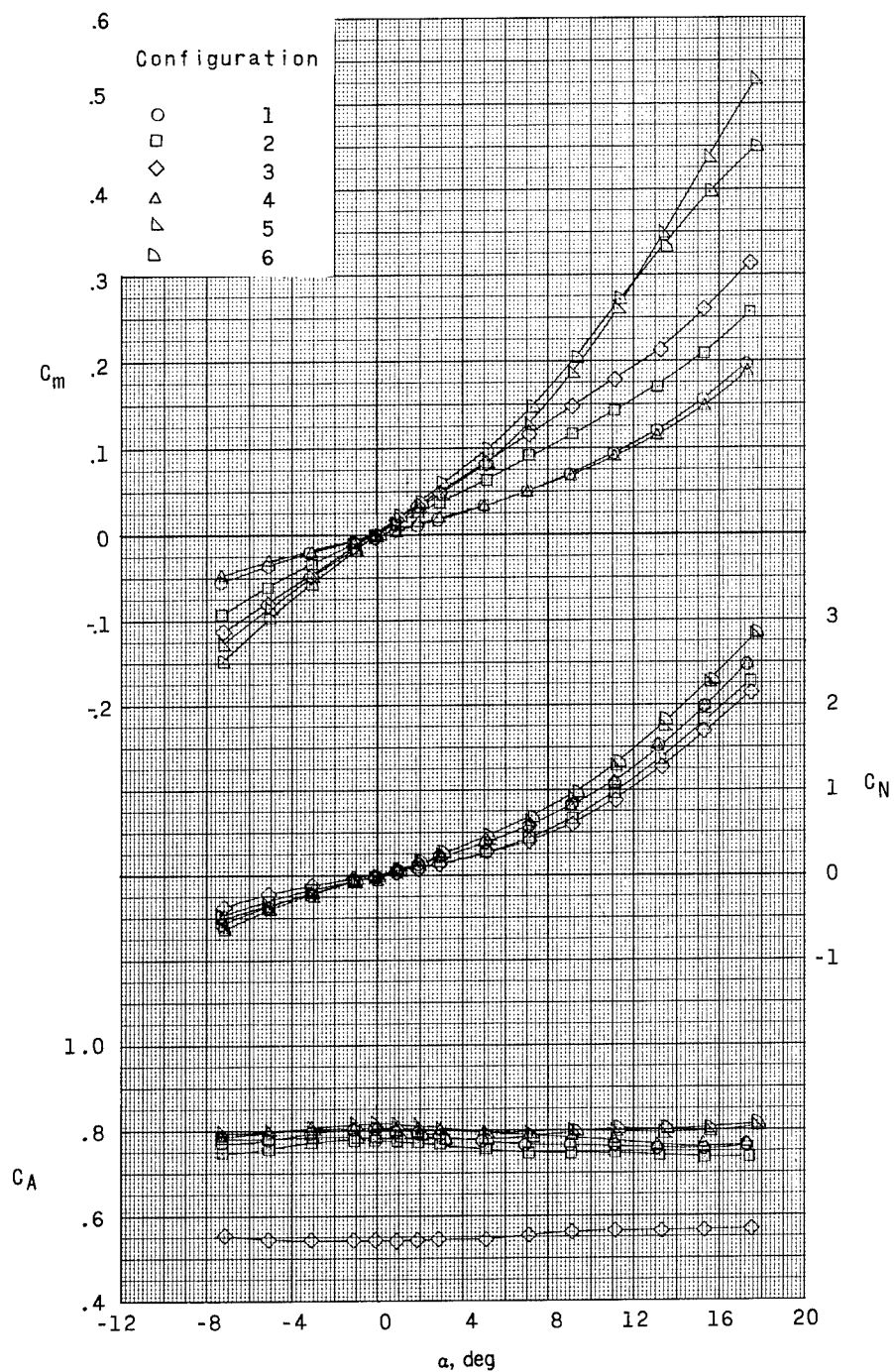
(c) M = 2.16.

Figure 5.- Continued.
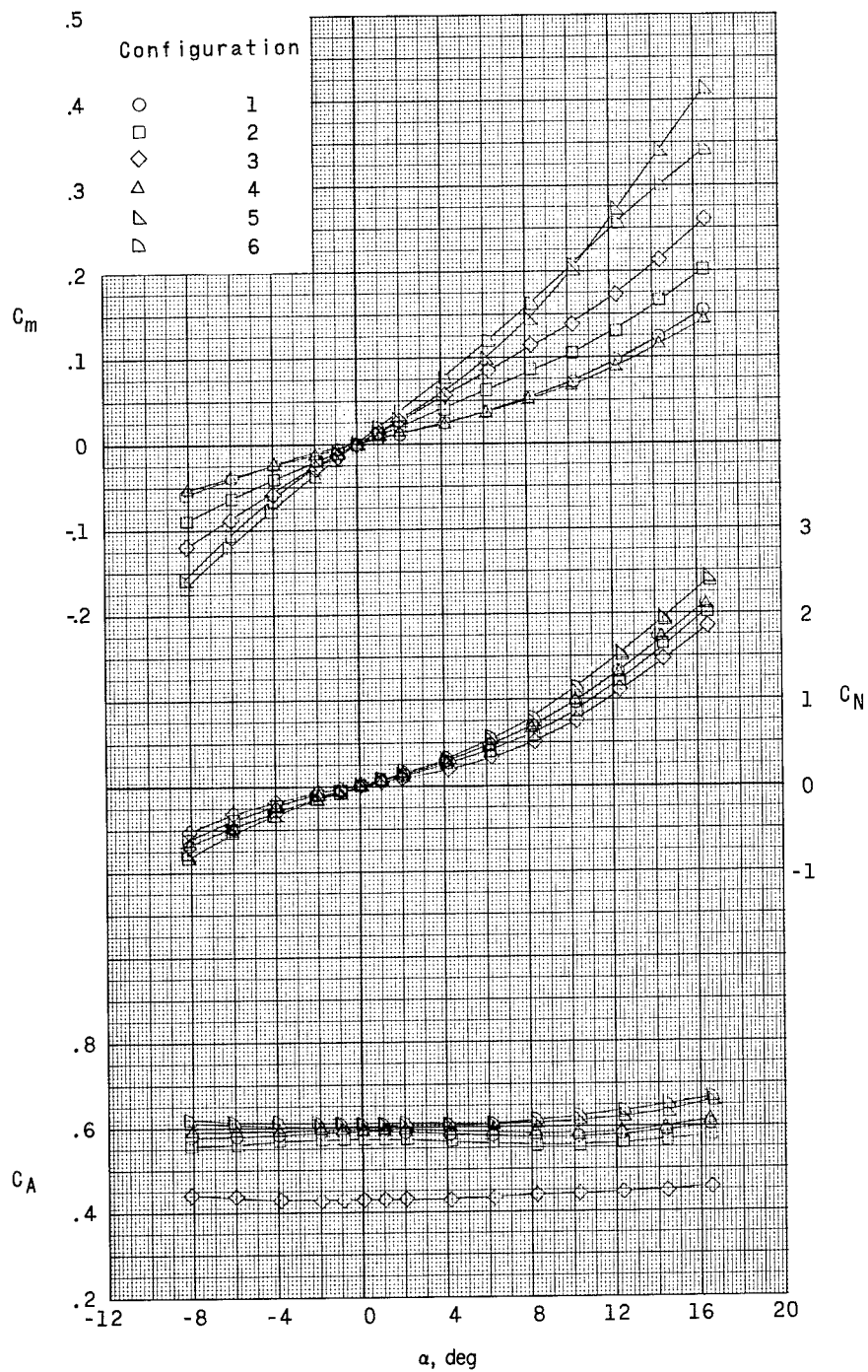
(d) M = 2.86.

Figure 5.- Continued.
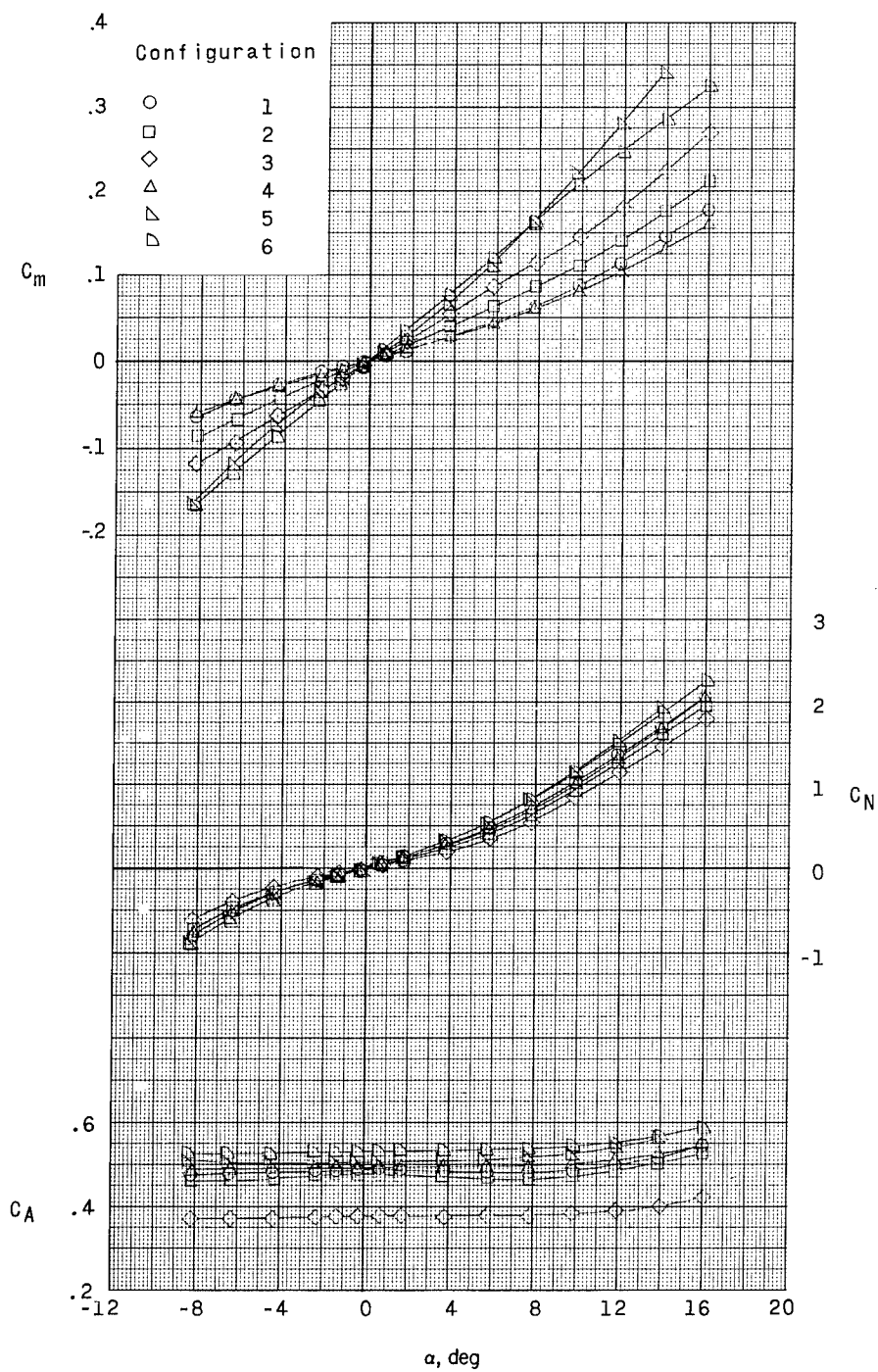
(e) M = 3.50.

Figure 5.- Continued.
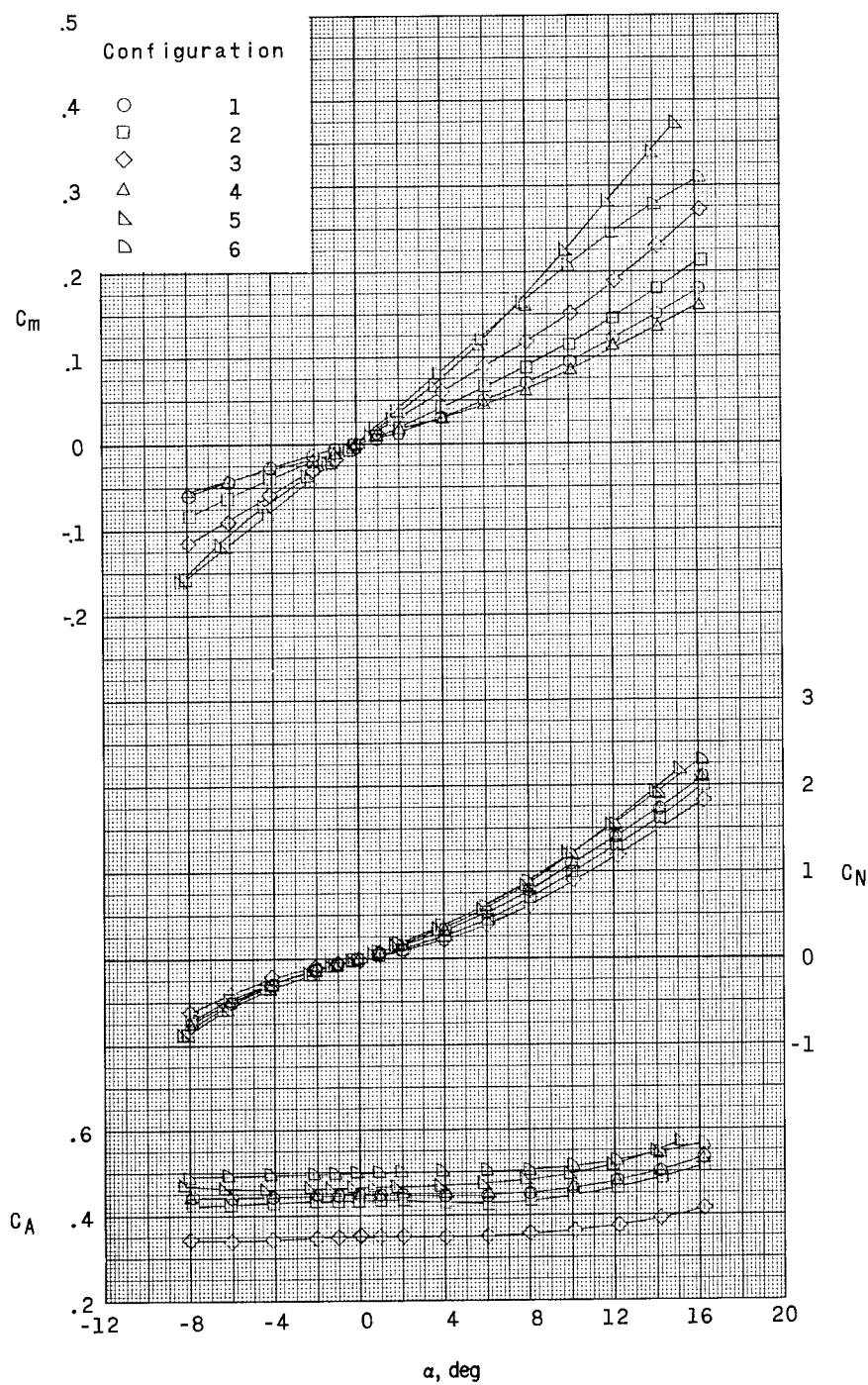
(f) M = 3.96.

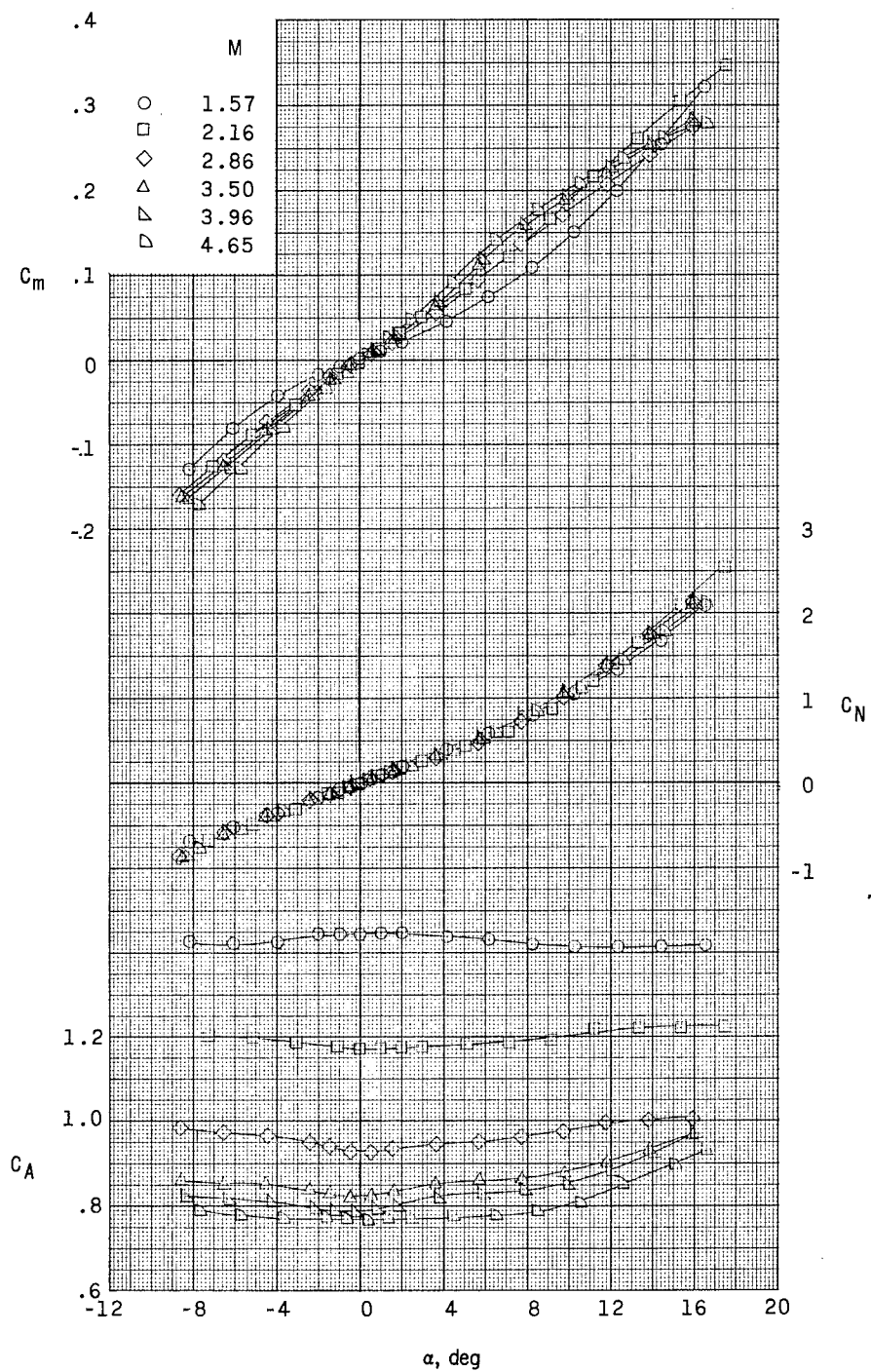Figure 5.- Continued.

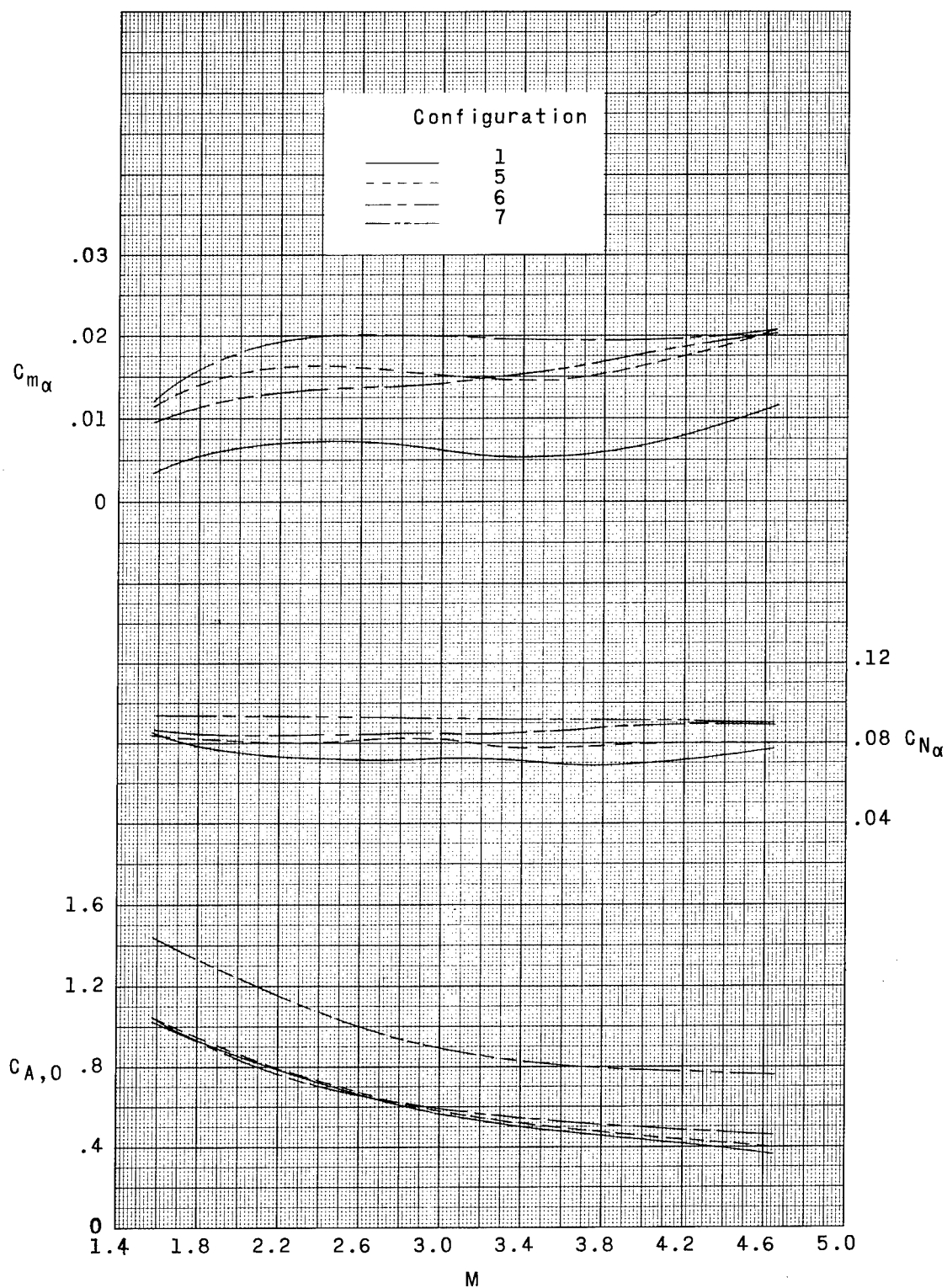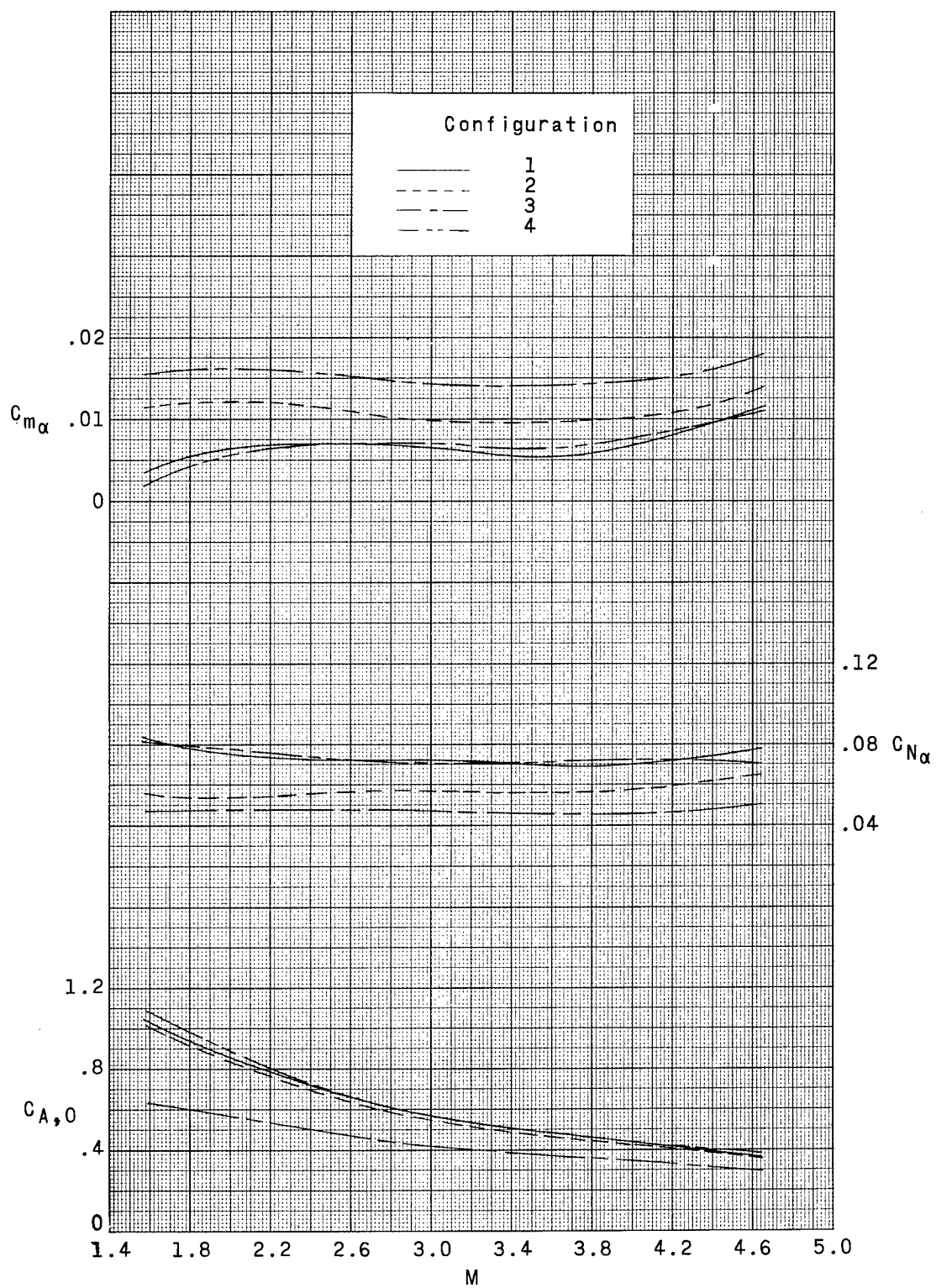(g) $M = 4.65$.

Figure 5.- Concluded.

Figure 6.- Aerodynamic characteristics in pitch of launch configuration with the space station (configuration 7).
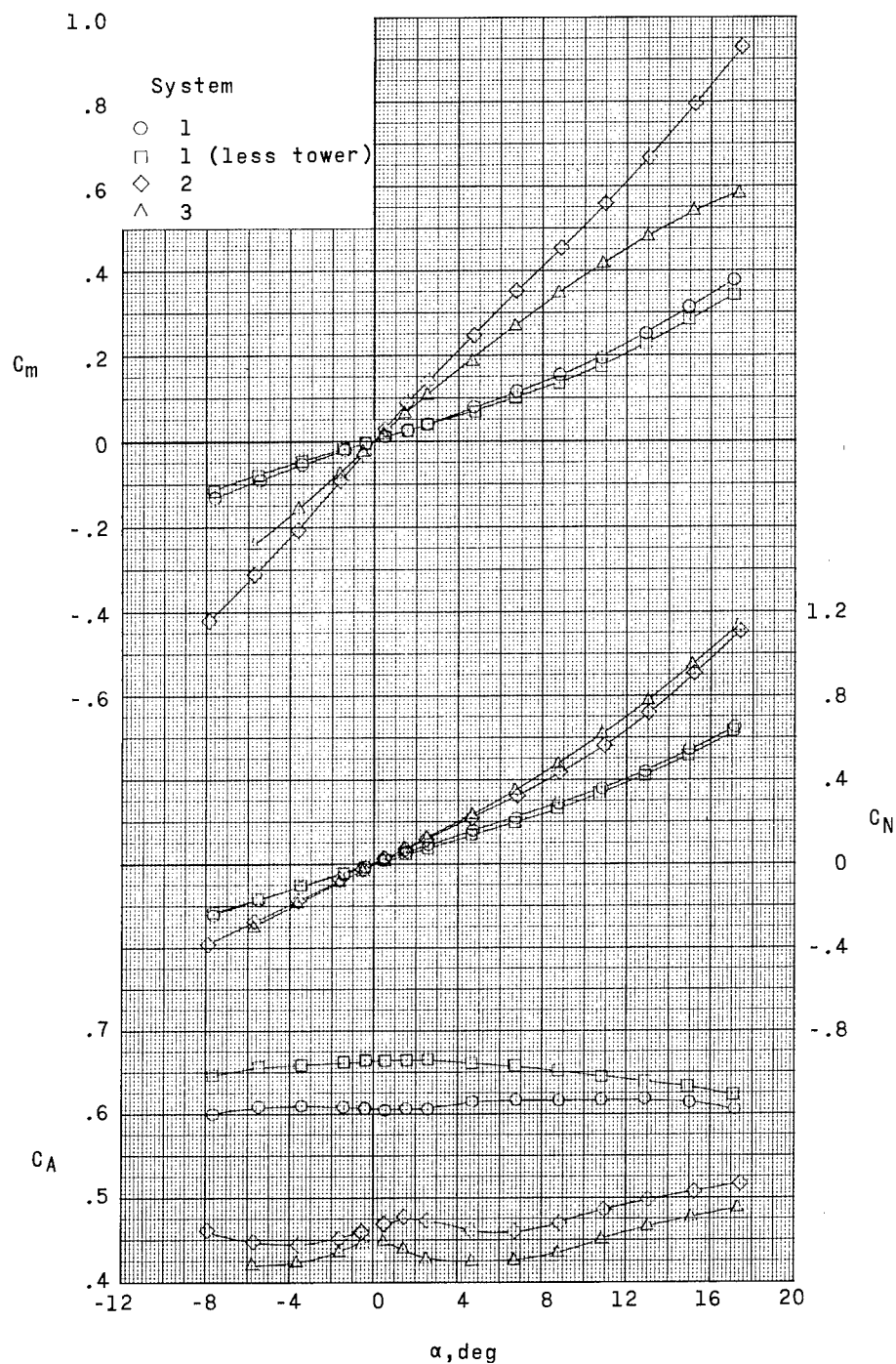
(a) Effect of third-stage spacecraft system.

Figure 7.- Summary of pitch characteristics for launch configurations 1 to 7.
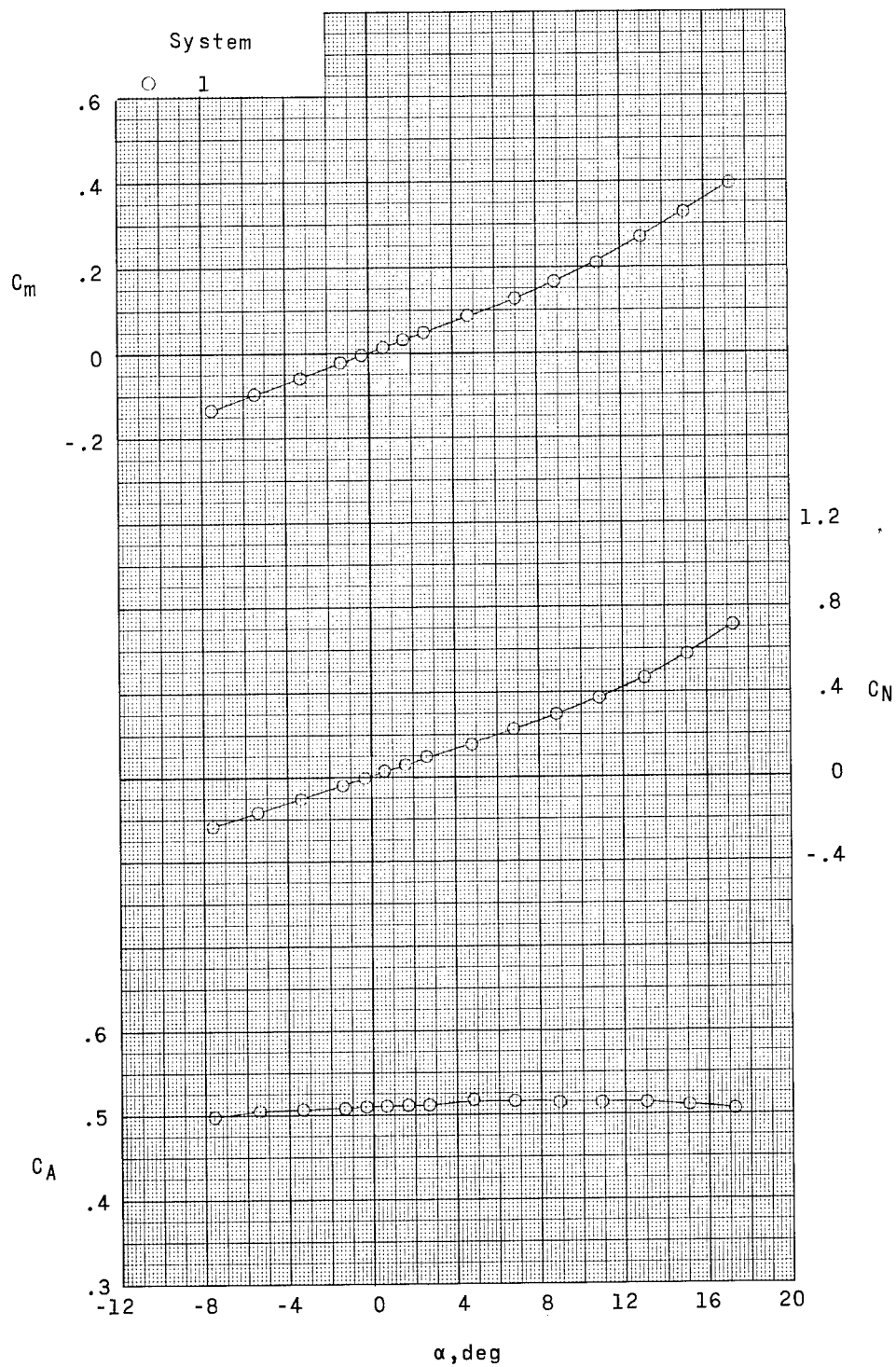
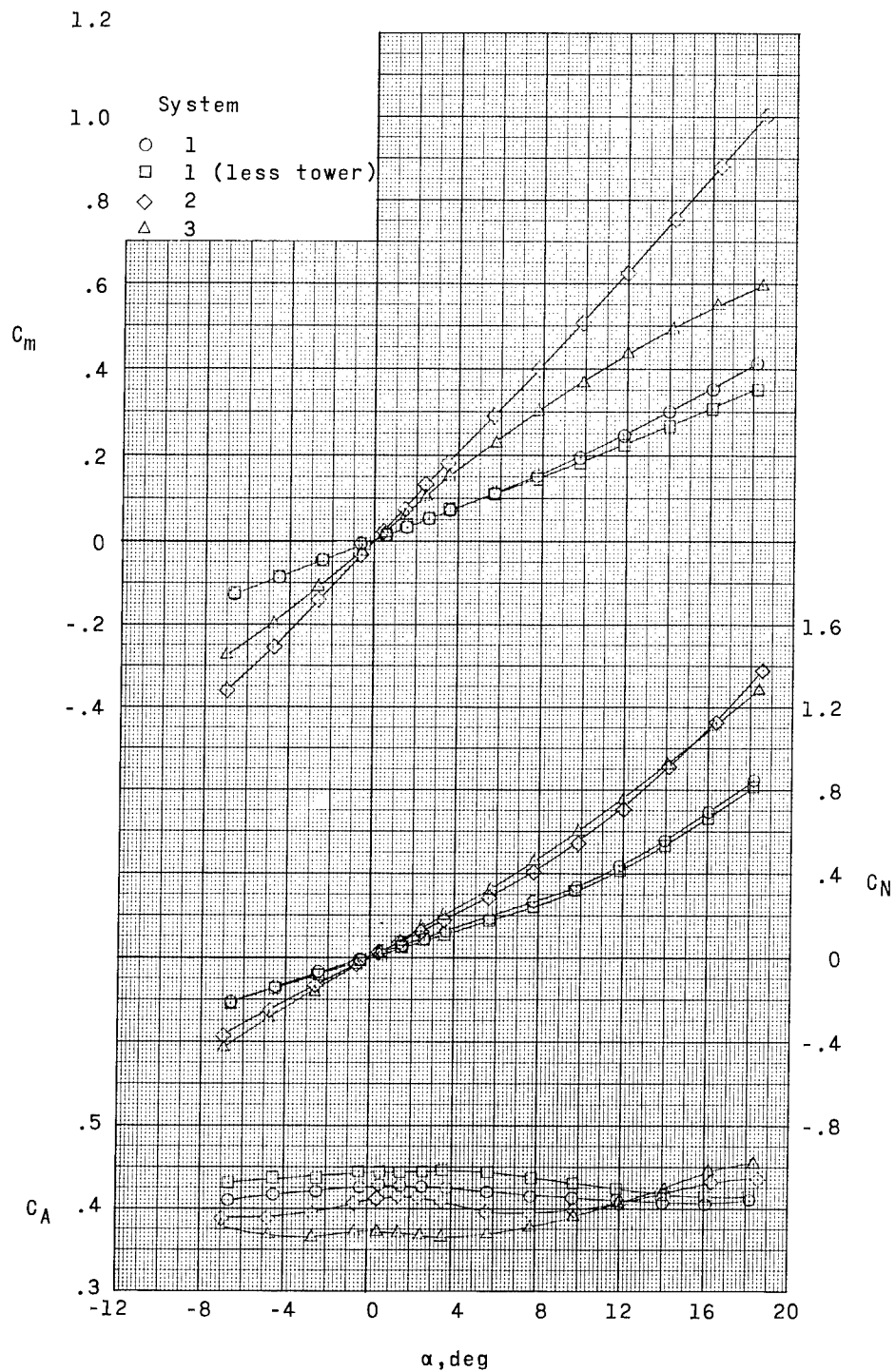(b) Effect of shrouds, fins, and tower.

Figure 7.- Concluded.

(a) M = 1.57.

Figure 8.- Aerodynamic characteristics in pitch of third-stage systems 1, 2, and 3 in the presence of the lower stages.
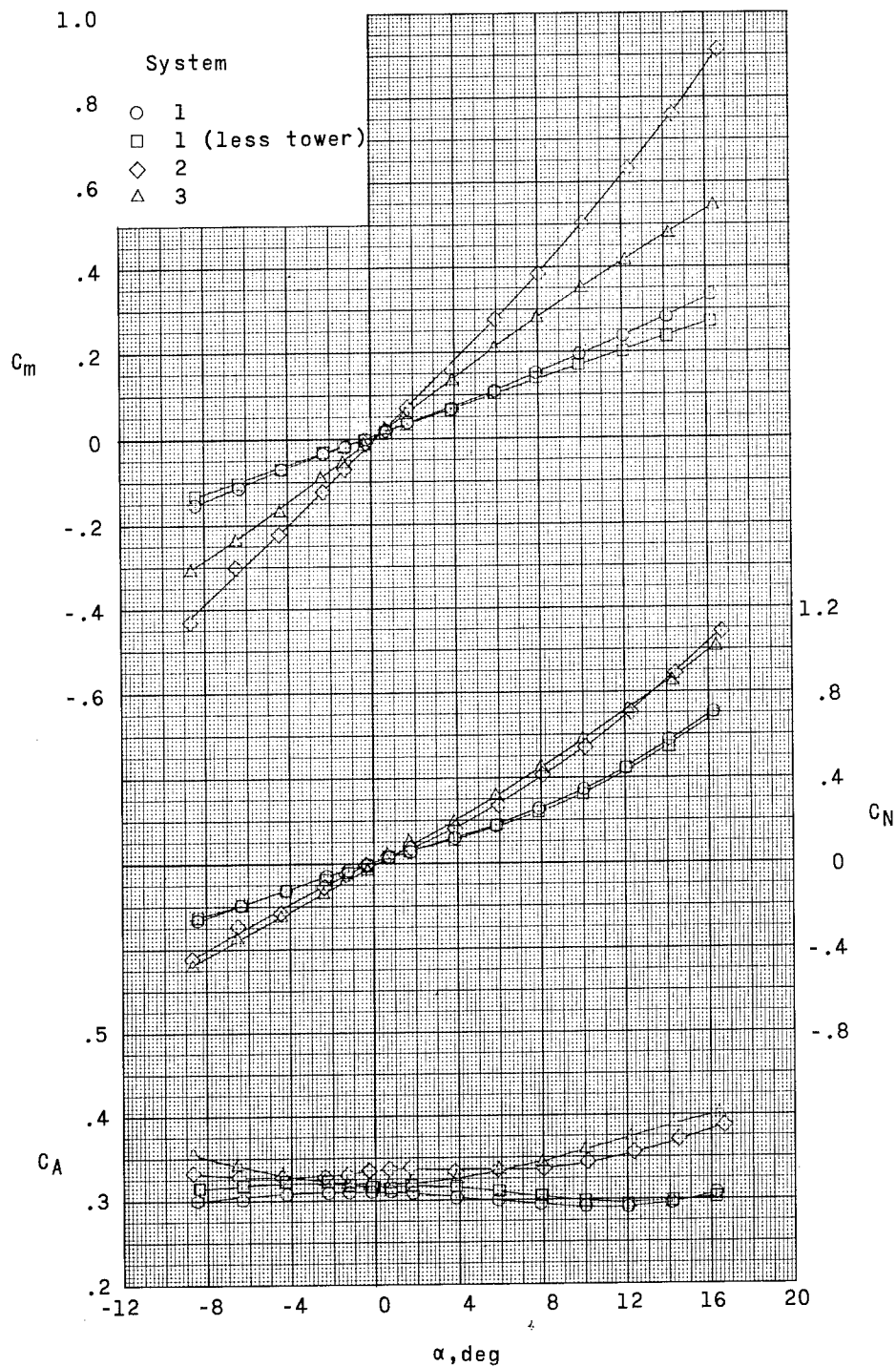
(b) M = 1.80.

Figure 8.- Continued.

(c) M = 2.16.

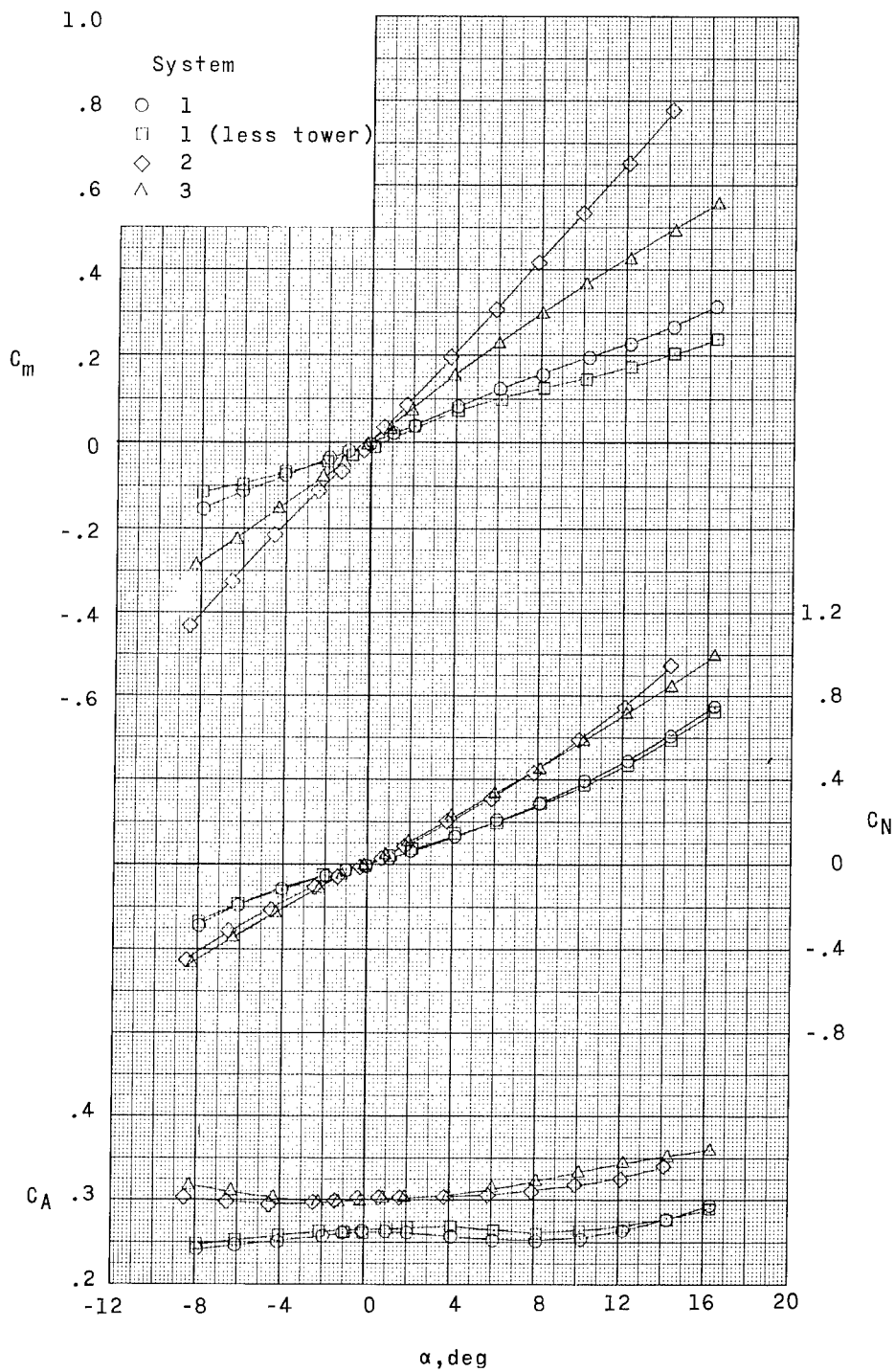Figure 8.- Continued.
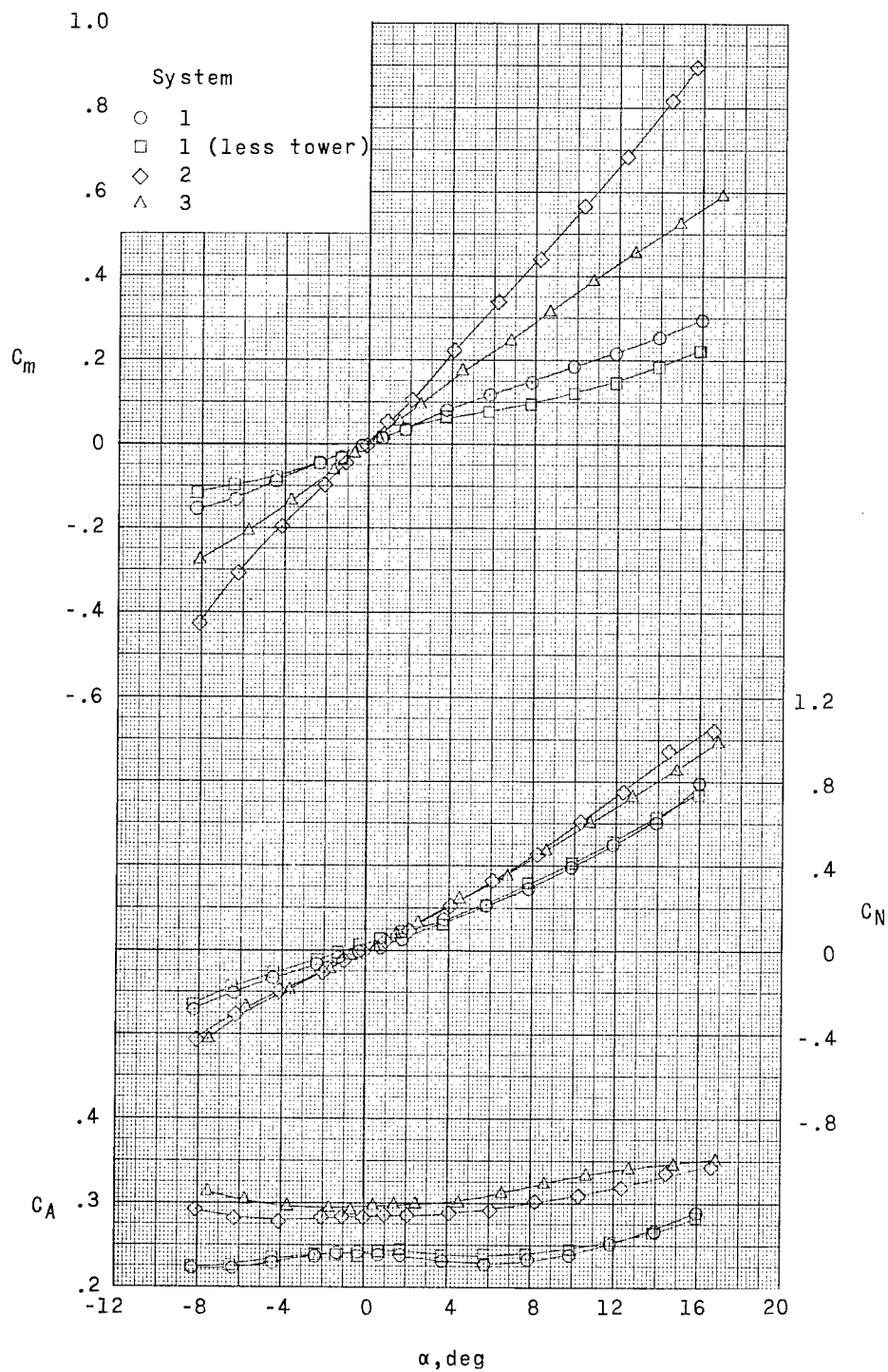
(d) M = 2.86.

Figure 8.- Continued.

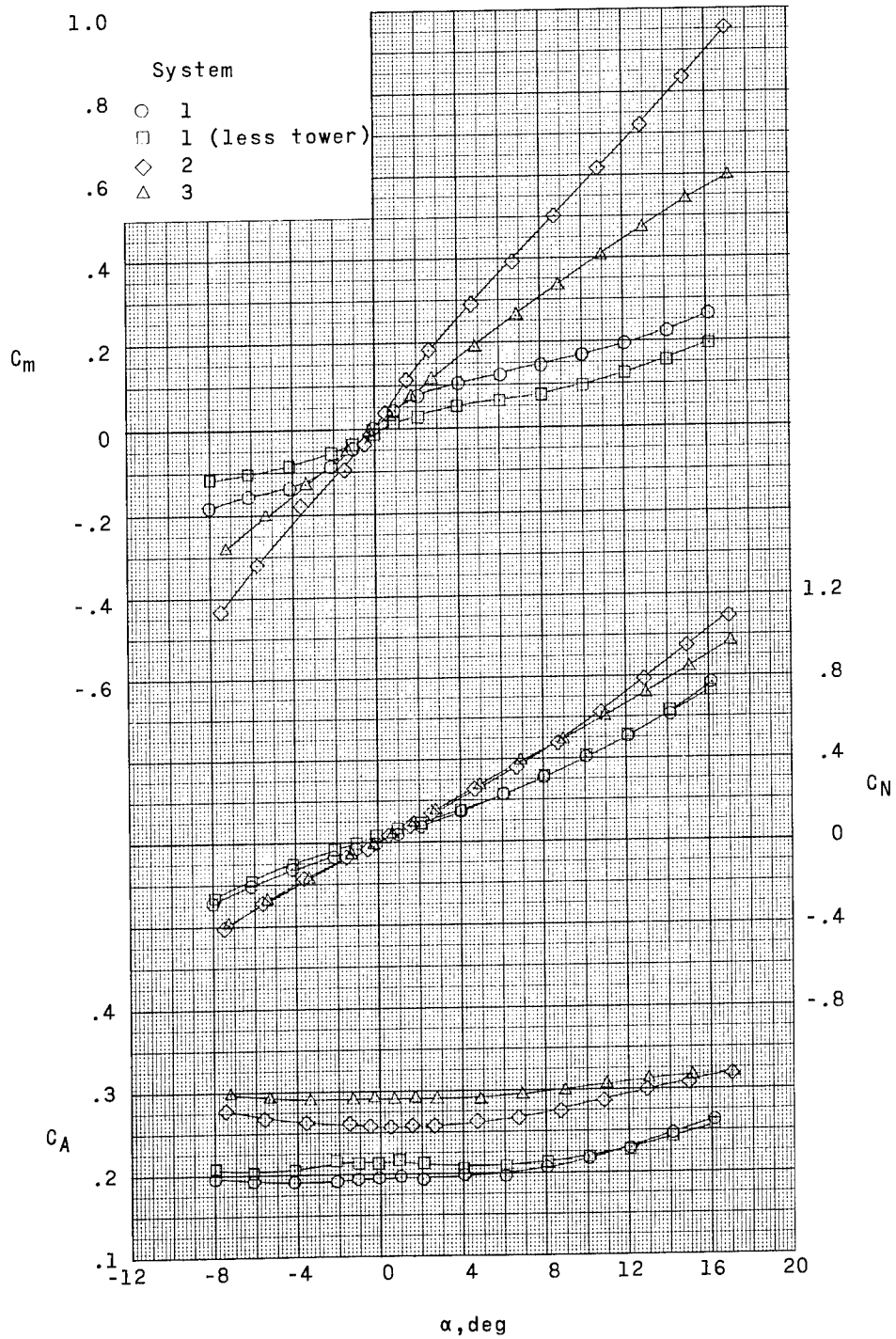(e) M = 3.50.

Figure 8.- Continued.

(f) M = 3.96.

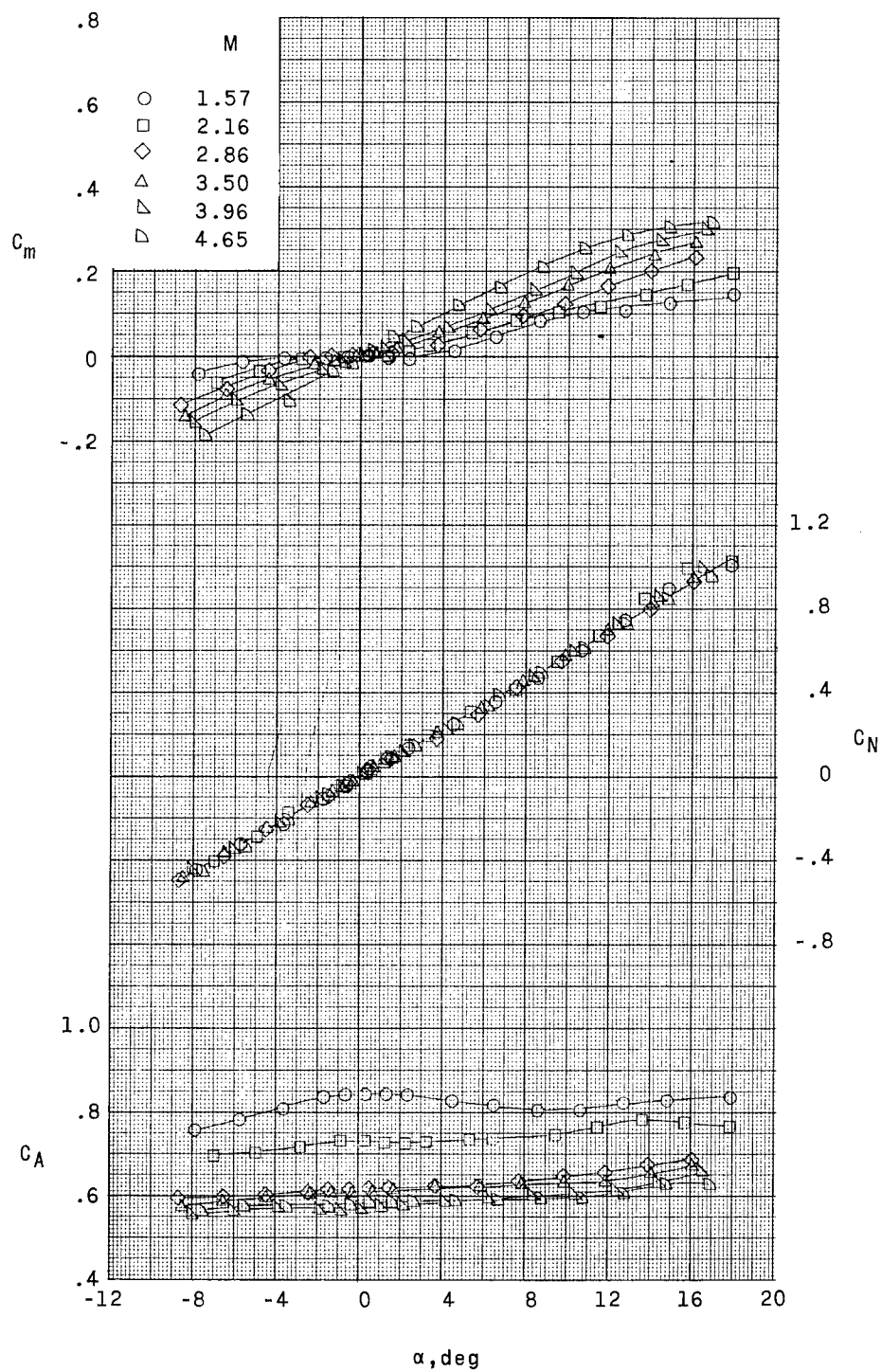Figure 8.- Continued.

(g) M = 4.65.

Figure 8.- Concluded.

Figure 9.- Aerodynamic characteristics in pitch of third-stage system 4 in the
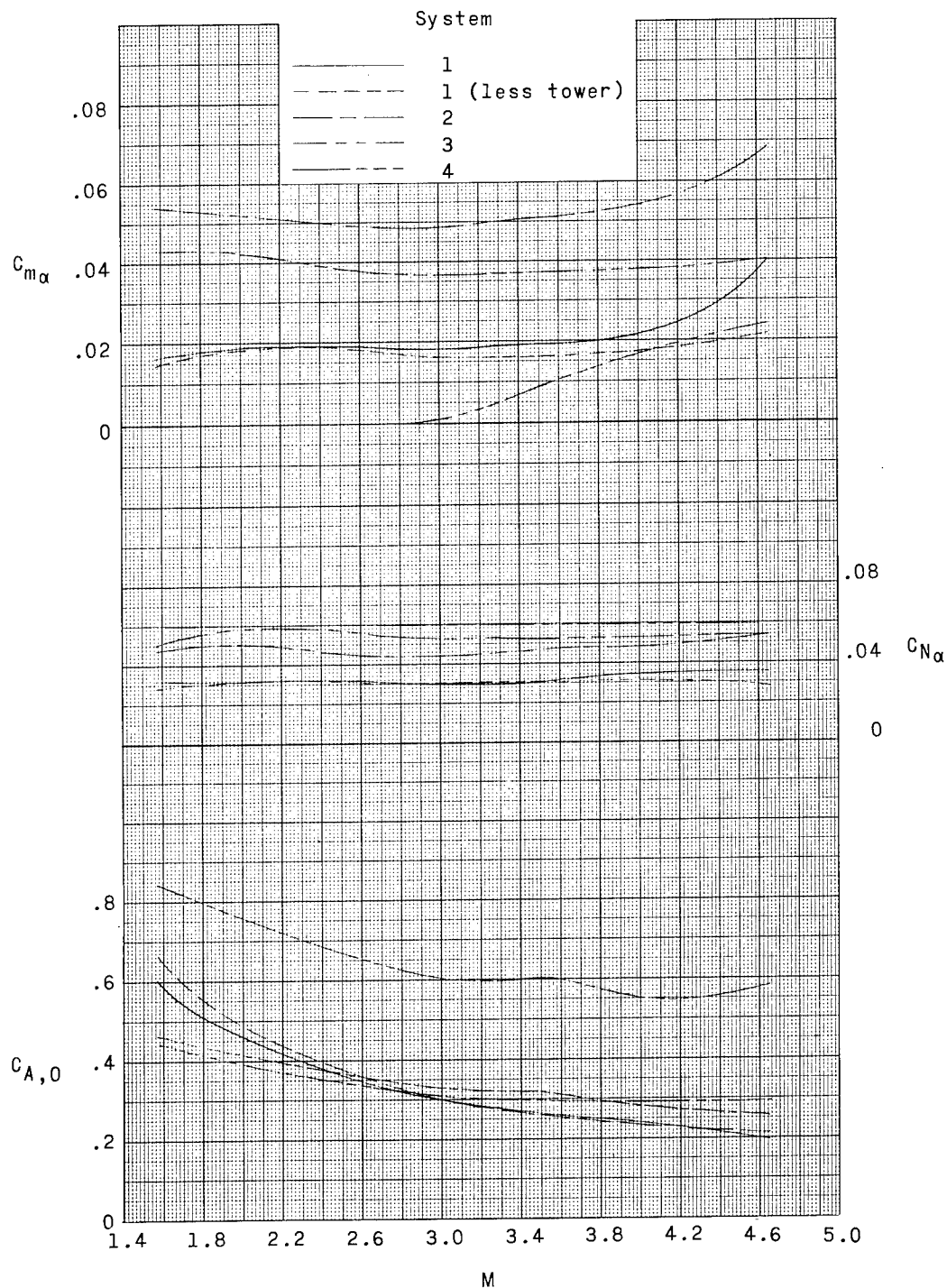presence of the lower stages.

Figure 10.- Summary of pitch characteristics of third-stage systems 1 to 4 in the presence of the lower stages.

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